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ON THE CHARACTER OF LARGE-SCALE MOTIONS IN THE SOLAR PHOTOSPHERE

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ABSTRACT

In reviewing the question of the character of large-scale motions on the Sun it is concluded that the motion in the solar photosphere is predominantly circulatory, which coincides with the results arrived at in ref. [8]. It is established that the characteristic dimensions of circulation vary with the phase of solar activity. While for the Northern hemisphere the dimensions decrease toward the solar activity minimum, the opposite takes place in the Southern hemisphere.

* * *

1. There are various opinions about the character of large-scale motions in the Sun's photosphere. Certain authors, such as for example Plaskett [1, 2], consider this as a hierarchy of turbulent motions, others, such as Bjerknes [3, 4] — that it is a circulation. Data on natural motions along latitude of nonrecurrent sunspot groups were processed in a series of works by one of the authors [5, 6, 7, 8]. It was shown on the basis of these investigations that the large-scale motions have a circulatory character.

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* K voprosu o kharaktere krupnomasshatbnykh dvizheniyakh v fotosfere Solntsa.

The object of the present work is to determine the character of large-scale motions by a method different from those applied earlier.

2. The Sun's photosphere matter may find itself in one of the following states of motion : 1) turbulent, 2) eddy and 3) circulatory. Possible also are combinations of these three forms of motion. Let us select for the characteristic of the type of motion the projection module in a direction passing through the points O_1 and O_2 of the difference $\Delta V_{1,2}$ of velocities at these two points. This difference is a specific function of the distance $\Delta r_{1,2}$ between the points O_1 and O_2, whose form is dependent on the type of motion. For example, in case of a turbulent motion

$$|\overline{\Delta V_{1.2}}| \sim (\Delta r_{1.2})^{1/3} \text{ [9, 10].}$$

It is practical to use for the pair of points O_1 and O_2 sunspots or the centers of gravity of sunspot groups, whether recurrent or not. For the application of that method, it is necessary to know the components of motion velocity by latitude as well as by longitude. We dispose only of data on the motion component along the latitude of sunspot group centers of gravity [5, 8]. We thus have to modify in a corresponding manner the method of velocity differences.

3. Assume that any large-scale stationary flows are absent in the photosphere matter (when speaking of photosphere matter motion we understand motions determined according to sunspot motion) We shall take for the direction $O_1 O_2$ the direction N — S, and we shall take the spots situated on any parallel to φ; we shall then project the velocity components of their motions by latitude on the meridian. Let us designate by V^i_φ the projection value, where i is the number of the spot and φ — the latitude. Let us form the mean value of velocity projection :

$$V_\varphi = \frac{\sum_i^n V^i_\varphi}{n}.$$

Since turbulent motions were considered, the quantity V_φ must be near zero and it must not depend on the latitude φ. (We assume that turbulent motions are equal at all latitudes). The smallness of V_φ follows from the fact that in turbulent motions direct and inverse motions have the same probability.

Let us compose the equation

$$\overline{|\Delta V|}_n = \frac{\sum_{j=1}^{n} |V_{\varphi_j} - V_{\varphi_j + \Delta\varphi}|}{n}; \qquad (1)$$

It it formed in the following fashion : we take the latitude interval $= {}^{\mathrm{I}+\mathrm{f}}\Phi - \Delta\varphi$, where is a certain fixed quantity. The whole latitude interval (φ_A, φ_B) for which quantities V_φ exist, is broken up into intervals . The breakup is done as follows : each following interval has is first point φ_j, 1° degree distant in latitude from the first point of the preceding interval (see Fig.1):

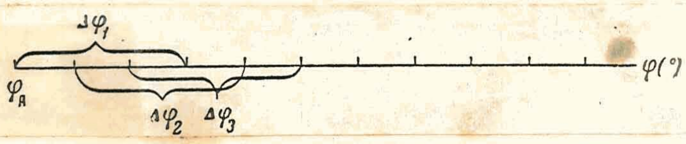


Fig.1

At such breaking up the first point of the first interval coincides with φ_A, and the last point of the last interval $\Delta\varphi$ coincides with φ_B. The quantity n which is the number of intervals laid into decreases with the increase of the quantity $\Delta\varphi$. The quantities $\varphi_A, \varphi_B, \Delta\varphi$ were also taken by us either as whole degrees or as a sum of a whole number and half a degree. That is why the quantity n is determined from the following expression

$$n = \varphi_A - \varphi_B - \Delta\varphi + 1.$$

4. The fundamental expression (1) acquires a different form, depending upon the type of motion. The criterion proposed by us for the determination of the type of motion of photosphere matter is precisely based upon that distinction.

a) The motion of photosphere matter has only a turbulent character. In this case V_φ must not depend on φ, i. e. V_φ is a random quantity oscillating within certain limits. This follows from the fact that all sorts of velocity values and directions exist in the turbulent as well as in an eddy motion. Therefore the quantity

$$V_\varphi = \frac{1}{n}\sum_i V_\varphi^i \longrightarrow 0 \quad \text{at } i \longrightarrow \infty.$$

Since in our case there is a finite number i of points, V_φ has a certain magnitude. The value V_φ for a neighboring quantity φ is casual. That is why the magnitude of the module of difference in (1) depends on φ as a random quantity, not dependent on the quantity $\Delta\varphi$. Let us designate the mean value of this random quantity by $\Delta\bar{V}$; we shall then have for any value of $\Delta\varphi$:

$$\overline{|\Delta V|}_n = \frac{n \cdot \Delta\bar{V}}{n} = \Delta\bar{V}.$$

Therefore, in the presence of only turbulent or eddy motion the quantity $V_n(\Delta\varphi)$ is dependent on neither n nor $\Delta\varphi$. Let us construct a graph by plotting in the abscissa axis $\Delta\varphi$, and in ordinate axis $\overline{|\Delta V|}_n$. The graph must present a straight line parallel to the abscissa axis in case of either turbulent or eddy motions. Naturally, a real graph will not present a precise straight line becuase of possible random deflections of the quantity $\overline{|\Delta V|}_n$ from the constant value. However, a smoothed average for such a graph must be sufficiently parallel to the abscissa axis.

b) Let us consider the case, when the motion of photosphere matter has the character of stationary motions. The possible various configurations of these flows will not now be taken into account. We shall assume that the quantity V_φ is a certain continuous function of φ. Then the difference $|V_{\varphi j} - V_{\varphi j+\Delta\varphi}|$ for various small values of $\Delta\varphi$ will also be small. Designating by $\Delta\overline{\overline{V}}$ the mean value of the derivative $\frac{dV_\varphi}{d\varphi}$ and taking out the expression $\Delta\overline{\overline{V}}\Delta\varphi$ beyond the sign of the sum, we obtain :

$$\overline{|\Delta V|}_{n\ \Delta\varphi\to 0} = \Delta\overline{\overline{V}}\cdot\Delta\varphi,$$

i.e. it is proportional to $\Delta\varphi$. However, for great values of $\Delta\varphi$ we may no longer consider that the difference $|V_{\varphi j} - V_{\varphi j+\Delta\varphi}|$ is proportional to $\Delta\varphi$. In the end the graph of $\overline{|\Delta V|}_n$ dependence on $\Delta\varphi$ is represented in the following form : a) for small values of $\Delta\varphi$ – by a section of straight line passing through the origin of the coordinates ; b) for great values of $\Delta\varphi$ it presents a certain dependence different from const. ; c) if there is a turbulent as well as a stationary motion, the graph of $\overline{|\Delta V|}_n$ dependence on must constitute a sum of graphs. Consequently it must be the curve of the case b), displaced in parallel with the abscissa axis.

Thus, we may judge on the character of the motion of photosphere matter by the shape of the graph of $\overline{|\Delta V|}_n$ dependence on $\Delta\varphi$.

Assume now that the stationary motion, or to be more precise, the dependence of V_φ on latitude, has a certain peculiarity with the period $\delta\varphi$. One may expect in such case that $\overline{|\Delta V|}_n$ will also have a peculiarity with the period $\delta\varphi$. Consequently, from the graph of $\overline{|\Delta V|}_n$ dependence on $\Delta\varphi$ we may determine certain characteristic dimensions in the stationary motion. In our case they will be the dimensions of the motion along latitude of the photosphere matter.

5. We utilized in the work data on mean motion velocities along latitude as a function of latitude of nonrecurrent sunspot groups, contained in the Table 1 of reference [5], with the introduced correction for the effect of boundary zones, and also part of data utilized in [8]. We computed the mean modules of the differences $|\Delta V|_n$ of mean motion velocities along latitude through latitude intervals $\Delta\varphi$. The latitude interval $\Delta\varphi$ varied from 1° to $20-25^\circ$. The computation of differences was conducted for each hemisphere separately and for a whole series of years in the cycles No. 12 and 13 of solar activity. After computation of mean modules of differences we constructed the graphs, where the quantities $\Delta\varphi$ were plotted in degrees in the abscissa axis, and $|\Delta V|_n$ (in degree/day) in the ordinate axis for the corresponding $\Delta\varphi$. After that smoothing was effected by the method of slipping mean values with a 3° interval and a 1° step. These smoothed curves are brought out in Fig. 2 and 3 for the Northern hemisphere of cycles No. 12 and 13, and in Fig. 4 and 5 for the southern hemisphere of the same cycles. The year to which the curve is related is indicated near each curve.

It may be seen from Fig. 2, 3, 4 and 5 (see next page), that the curves run obliquely to the abscissa axis. Such course of the curves, as compared with the considerations developed in para 4, points to a circulatory character of large-scale motions. Thus the conclusion derived by the method of extremum identification [8] is being corroborated, and is a new confirmation of the correctness of the method.

Comparison of the general character of the curves in Fig. 5 with that of Fig. 6, borrowed from reference [8], shows that a lesser clarity of the curves for the Southern hemisphere of the cycle No. 13 coincides with the fact that the directions of extremum shifts in the Southern hemisphere vary all the time, whereas in the Northern hemisphere they are more steady, and this coincides with a good expressiveness of the curves for the Northern hemisphere.

It is visible that the curves for the Southern hemisphere are better expressed for the years of cycle No.12 than for those of the cycle No.13. This coincides with a greater stability of directions of extremum displacement in the Southern hemisphere of the cycle No.12.

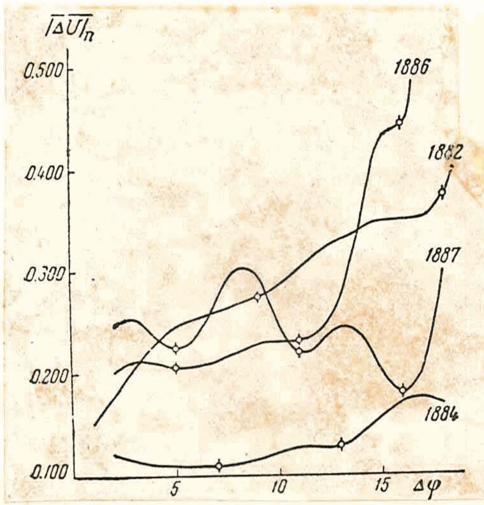


Fig. 2

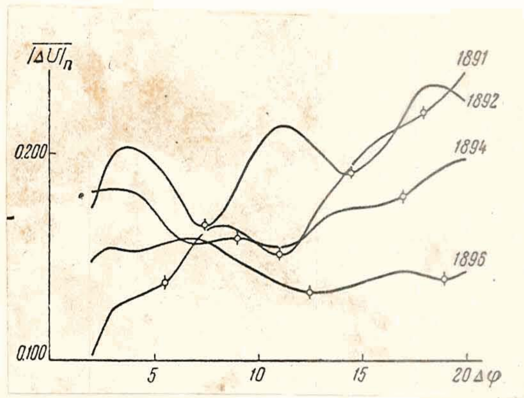


Fig. 3

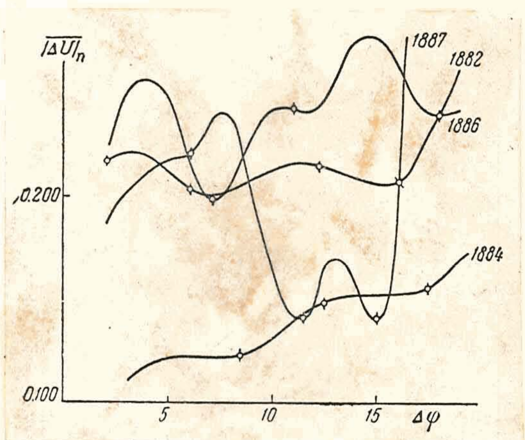


Fig. 4

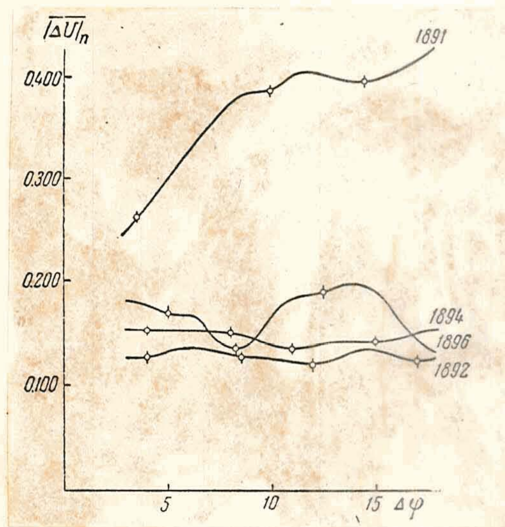
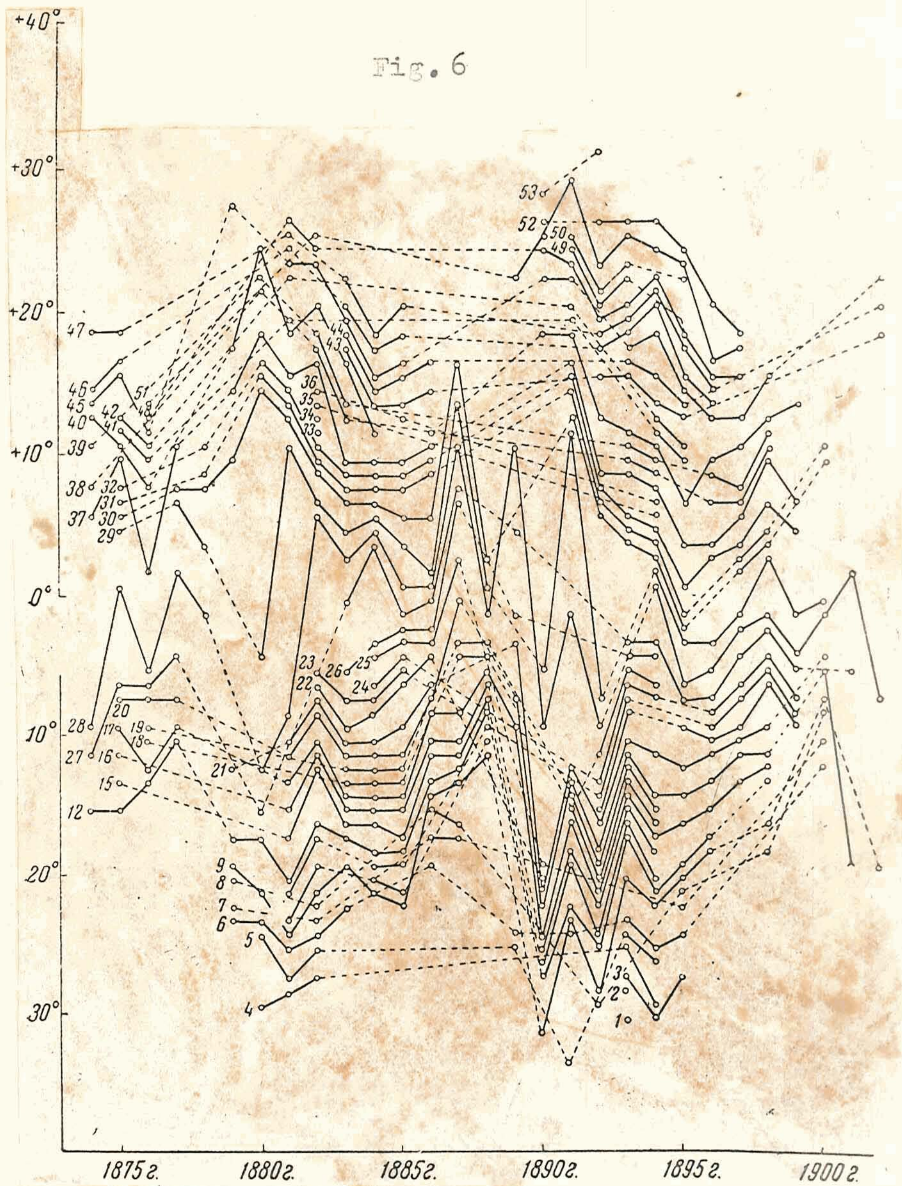


Fig. 5

Such agreement of various characteristics of photosphere matter motion, obtained by different methods, leads to the conclusion of correctness of both methods.

A lowering of the curve is visible at certain places of the Figures 2, 3, 4, 5. Such lowerings relative to the general course take place for all curves. The bascissa values of the middle parts of these lowerings (marked by vertical traits) are plotted in Fig. 7 for the Northern hemisphere and in Fig. 8 for the Southern hemisphere. Years are plotted in the abscissa axis on all these drawings and the values of bascissa of the middle of lowerings — in the ordinate axes of Fig. 2, 3, 4 and 5.

Fig. 6



The dimensions of the rectilinear part of the flow were computed in [11]. There no subdivision by hemispheres and by years of solar activity cycle was effected. Because of that the dimensions of the rectilinear part of the flow obtained in [11] constitute mean dimensions, coinciding with the mean value of the ordinate of the lower curve of Fig. 7. The ordinates of that curve vary from 5 to 13°, which gives 9° as an average or, converting into kilometers, 100 000 km. This quantity agrees well with the estimate given in [11].

Therefore, if one considers that positions of the minima correspond to the characteristic dimensions of the circulation, the curves of Fig. 7 and 8 give the course of variation of these dimensions with the phase of the solar cycle. These dimensions are (?) multiples of the least.

It may be seen that the characteristic dimensions of circulation vary with the phase of the solar activity cycle. At the same time for the Northern hemisphere they decrease toward the solar activity minimum, and for the Southern hemisphere — they increase.

The curve of mean annual values of daily relative numbers is plotted in Fig. 9.

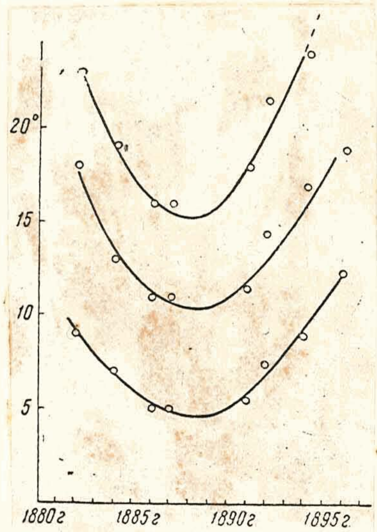


Fig. 7

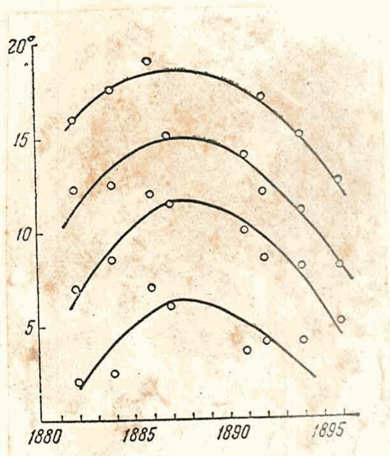


Fig. 8

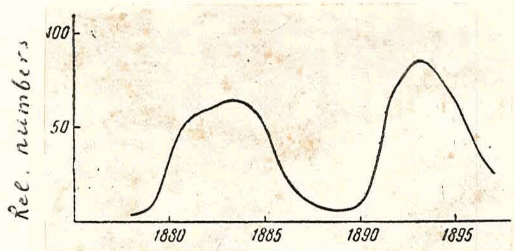


Fig. 9

As a result of the current work the following conclusions can be derived :

1. Large-scale motions in the solar photosphere have apparently a circulatory character, which agrees well with the conclusion reached in [8].

2. The characteristic dimensions of the circulation vary with the phase of solar activity, with the dimensions decreasing toward the solar activity minimum in the Northern hemisphere, and increasing in the Southern hemisphere.

3. The least clarity of the curves of $\overline{|\Delta V|}_n$ dependence on $\Delta\varphi$ is observed at places where the directions of extremum shifts of velocity field obtained in [8] vary more frequently.

***** THE END *****

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